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Influence of a large urban park on the local urban thermal environment

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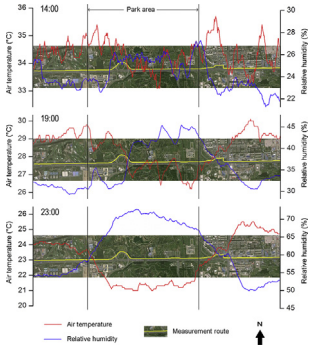
HIGHLIGHTS

- We study the cooling effects of a large park and observed significant cooling effects.
- The park was 0.6 to 2.8 °C cooler than the surrounding urban environment.
- The park cooling was variable but could extend almost 1.4 km beyond the park's border.
- Large differences in temperature exist both within the park and surrounding urban areas.
- The air temperature differences depended strongly on land cover features of each site.

GRAPHICAL ABSTRACT



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ABSTRACT

Green areas in the city can greatly improve the outdoor thermal environment, as well as mitigate the urban heat island effect by reducing summer air temperature. In a context of climate change, with the expected increase in temperature and intensity of heat waves, cooling by green areas is set to become increasingly important. In this study, field observations were carried out to investigate the thermal performance of a large urban vegetated park and its influence on thermal environment of the surrounding urban areas in Beijing, China. Measurements were conducted along a selected path during three summer days with clear skies and light winds by mobile traverses. The results showed that the park was cooler than the surrounding urban areas both during the daytime and at night. The mean air temperature differences between the park and the surrounding areas were in the range of 0.6–2.8 °C at different times, with a maximum of 4.8 °C observed at midnight. The results also found that as the distance from the park border increased, the ambient air temperature exhibited a gradually increasing trend. This indicated the park has a cooling effect on the urban environments adjacent to the park, and this cooling effect extended approximately 1.4 km from the park boundary. The air temperature variations also depended strongly on the land cover characterizing the immediate environment of the measurement sites. Increasing the percent vegetation cover could significantly decrease air temperature, while the increase of percent impervious surface area would significantly increase it.

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1. Introduction

In the last decades, a great concentration of people around urban areas took place worldwide, especially in developing countries. Presently, more than half of the world's population lives in urban areas and this value is set to increase to 66% by 2050 (United Nations, Department of

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Economic and Social Affairs, Population Division, 2014). The urbanization process, with its fast population increase and urban expansion, results in significant modifications in the urban climate (Kalnay and Cai, 2003). The most obvious feature of urban climate is the urban heat island (UHI), which refers to the phenomenon of higher air and surface temperatures occurring in urban areas than in the surrounding rural areas (Oke, 1982; Voogt and Oke, 2003). Increased temperatures due to UHI may affect the inhabitability of cities, worsen air pollution and increase cooling energy consumption (Sarrat et al., 2006; Tan et al., 2010; Kolokotroni et al., 2006; Chen et al., 2016). In addition, the increased energy consumption under warm conditions not only violates the principles of urban sustainability, but also contributes to the global warming. With rapid urbanization, the urban heat island will affect a larger number of urban residents (Grimmond, 2007). Therefore, there is a pressing need for urban researchers to evaluate strategies that may mitigate against further increases in temperatures in urban areas.

There are several strategies to provide cooling in cities, such as increasing urban vegetation, using cool roofs and cool pavements (Rosenfeld et al., 1995). Among all the cooling measures, urban greening has been always recommended as an important adaptation strategy and significant approach to regulate urban air temperatures and reduce the health related consequences of increased air temperatures (Givoni, 1991; Gill et al., 2007; Brown et al., 2015; Jamei et al., 2016). Urban green areas such as parks can ameliorate UHI effect by the combined impact of shading and evapotranspiration (Oke et al., 1989; Jonsson, 2004). Extensive field based measurements have demonstrated that urban parks are usually 0.5–4 °C (Jauregui, 1991; Ca et al., 1998; Chang et al., 2007; Jansson et al., 2007; Lee et al., 2009; Cohen et al., 2012; Skoulika et al., 2014; Doick et al., 2014; Sugawara et al., 2016), and sometimes even 5–7 °C (Spronken-Smith and Oke, 1998; Upmanis et al., 1998; Oliveira et al., 2011), cooler than their surrounding urban built-up areas. This phenomenon of patchy, cooler green areas within the urban environment is often called "park cool island" (PCI) (Barradas, 1991). Previous studies in relation to the PCI effects usually focus on investigating the temperature difference inside an urban park compared to an urban area either in the park surroundings or elsewhere in the city, with much fewer studies examining the spatial form of PCI or the cooling effect of urban parks on the surrounding urban environment (Bowler et al., 2010).

The cooling effect of urban park not only creates a relatively comfortable thermal environment in the park for the rest and recreation of city residents but also, more importantly, influences the surrounding urban area through convection and diffusion. In addition to significantly improving the urban thermal environment and reducing energy consumption by buildings, the cooling effect is also a manifestation of macroscale ecological benefits exerted by green spaces. Several studies have revealed that the cooling effect of parks could extend into the surrounding urban areas. In Mexico City, Jauregui (1991) found that the cooling effect of a large park (~500 ha) reaches a distance of up to 2 km, about the same as its width. Ca et al. (1998) did some field measurements to determine the cooling effect of a park on the surrounding area in the Tama New Town, a city in the west of Tokyo. The results indicated that with a size of about 0.6 km^2, the park can reduce by up to 1.5 °C the air temperature in a busy commercial area 1 km downwind. Other relevant studies also indicated that urban park have a cooling effect on the surrounding environment (Upmanis et al., 1998; Spronken-Smith and Oke, 1998; Shashua-Bar and Hoffman, 2000; Chen and Wong, 2006; Hamada and Ohta, 2010; Doick et al., 2014).

However, the thermal performance of a park and its influence on the surrounding urban areas is not only affected by the characteristics of park itself, but is also affected by the surrounding urban features, such as local urban morphology around the park, sky view factor (SVF), spatial location, and land cover features (Chang et al., 2007; Lee et al., 2009; Lau et al., 2012). Because these characteristics and factors can all be adjusted and controlled through reasonable planning and design, an investigation into the intensity and range of the cooling effect for urban parks and their primary influencing factors is required to formulate a theoretical basis to scientifically and reasonably plan and design urban parks, thus maximizing the degree to which the "cool island effect" of urban green areas is achieved. However, there are too few studies that explicitly examined this, for example by analyzing and presenting data at increasing distance from the park boundary, to be able to speculate on the strength and shape of this relationship (Bowler et al., 2010). Therefore, further empirical research is required in order to better understand all the different factors that explain the influence of the green areas on the surrounding environment, providing the necessary feedback to planners to improve the characteristics and spatial arrangements of parks in urban areas, taking into consideration the specific features of each city.

The present paper analyses the field measurements performed in and around a large urban vegetated park in northern Beijing, China, during hot summer weather conditions. The aim of this research is to investigate the thermal performance of the large park and its influence on the thermal environment of the surrounding urban areas. The specific objectives of this research were:

(1) to present data illustrating the air temperature differences between the park and its urban surrounding, as well as variations within the respective environment;
(2) to investigate the intensity and range of the cool island effect from the park into its immediate surrounding urban areas;
(3) to analyse if the urban environment characteristics, such as spatial location and land cover feature have an influence on the air temperature of each measurement sites.

2. Methodology

2.1. Study area and site description

Beijing (39°56′ N, 116°20′ E), the capital of China, is located in the northern part of the North China Plain. It is the second largest city in China with a total population of 21.7 million by the end of 2016. It has a monsoon influenced humid continental climate characterized by hot and humid summers and generally cold, windy and dry winters. According to the climatological normals (1971–2000), January is the coldest month with an average temperature of −3.7 °C, while July is the hottest month with an average temperature of 26.2 °C. The main wind direction is from southeast to northeast in summer and in reverse during winter. Since 1978, Beijing's urban population and the extent of the urban built-up area have been gradually increasing. This urbanization process, with its increasing built-up areas and anthropogenic activities, results in significant modifications in the underlying surface properties and the quick increase in the intensification of the UHI effect.

This study was conducted in and around Beijing Olympic Forest Park (BOFP), which is located in the northern end of Central Axis of Beijing city. With a total occupation of 680 ha, the park is the largest public green area ever built in Beijing. The Park with hills, forest, lakes, wetland and other natural landscapes as its main part has become the green park and called the green lung of the Beijing city. The 5th Ring Road divides the park into a southern part (380 ha) and a northern part (300 ha). Measurements were conducted along a side road passing through the BOFP and its surroundings urban areas. The side road is oriented in an east-west direction and has virtually no anthropogenic heat sources. The vehicle traffic is not intense and its impact on the air temperature would be negligible.

The whole measurement route was divided into two routes with respect to their different greenery and building distribution conditions. To make the data spatially comparable, 31 equidistant measurement sites were chosen with the intention to investigate the quantitative relationship between air temperature and environment characteristics of each location (Fig. 1). These measurement sites located sufficiently close to one another to be affected by uniform meso-scale climate conditions,

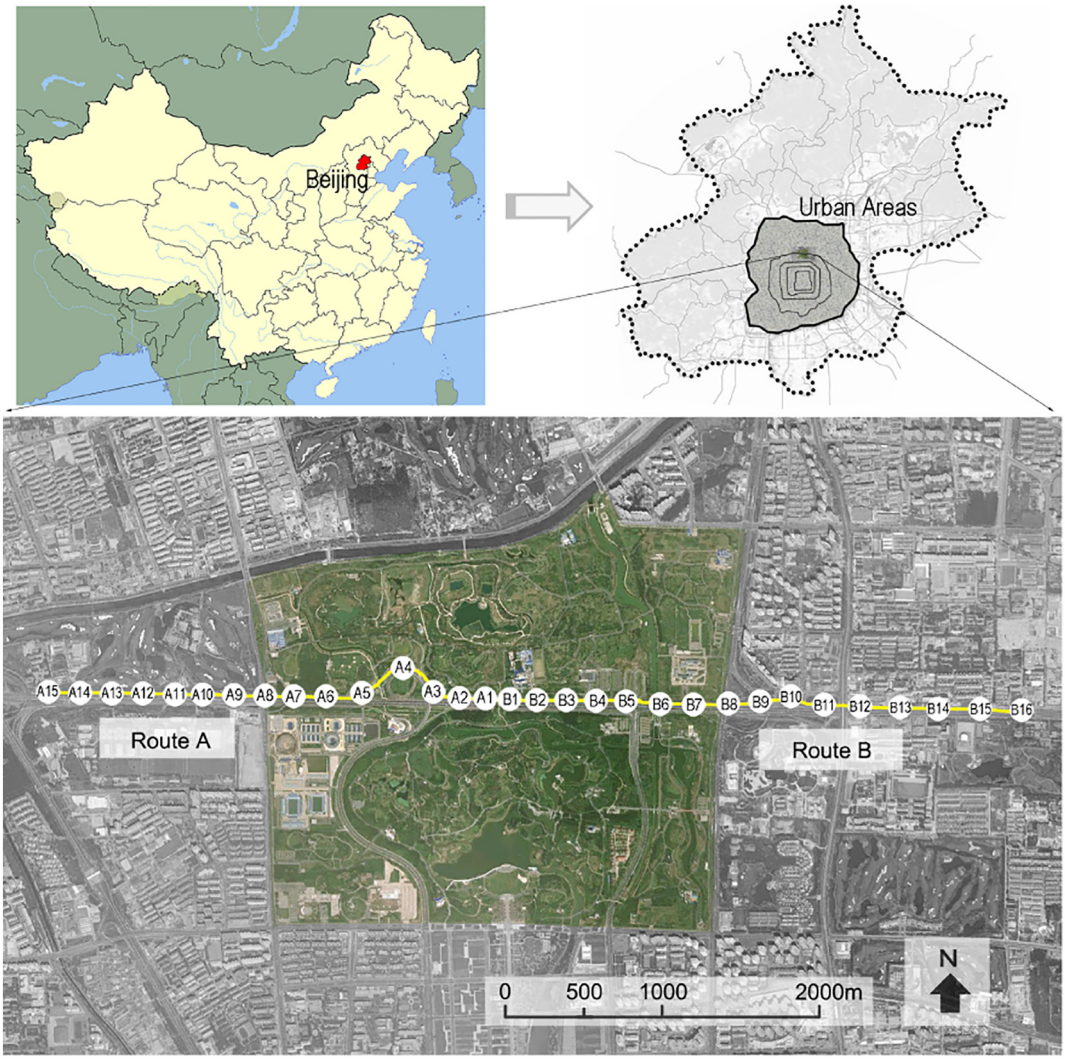
Beijing
Urban Areas
A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15 B16
Route A
Route B
0 500 1000 2000m
N

Fig. 1. Study area and the location of measurement sites.

and yet, also affected by distinctly different micro-scale landscape characteristics.

2.2. Air temperature measurements

Mobile traverses were used to conduct air temperature measurements in the summer of 2010. Survey times were afternoon (14:00–15:00), evening (19:00–20:00) and midnight (23:00–00:00). All observations were carried out during clear and windless days, i.e. when the park cool island effects could be expected to be most pronounced. Avoidance of windy and cloudy conditions also minimizes the influence of meteorological variables. Measurements were conducted in open areas with direct solar radiation.

Measurements of air temperature were taken using a mobile station with a thermistor temperature sensor connected to a data logger with a precision of 0.1 °C along the measurement route. The temperature sensor was fitted within a radiation shield, which mounted onto the front of a bicycle at 1.5 m above ground level. A GPS travel recorder was used to note geographical coordinates of latitude, longitude, and altitude synchronized to observations. A fixed weather station was installed in the park center for recording of the daily trend of air temperature. These data were used to correct the values taken with the mobile station because the measurements at different sites were not instantaneous. Each traverse took approximately 25 min to complete, during which data were logged every second. After completing the transect and reaching the final site, all the measurements were repeated in the opposite direction. To make the data spatially comparable, all temperature data were adjusted to a central time between the 'back and forth' transect and an average of the 'back and forth' observations was made (Jansson et al., 2007). Wind speed and direction were obtained from the weather observatory station near the measurement sites. In most cases, the wind does not change significantly during the individual measurement session.

2.3. Measurement and computations of landscape parameters

Urban features influence the behavior of the weather variables. Numerous landscape parameters have been developed to assess and quantify the effects of urban environment characteristics on air temperature. In this study, all of the measurement sites, located in a street with consistent *E*-W orientation, have similar urban geometry with SVF range from 0.76 to 0.93. Therefore, two categories of landscape parameters including spatial location and land cover feature, were selected to measure site environmental characteristics. Spatial location was measured using distance to the park border. Land cover features included the percent vegetation cover and the percent impervious surface.

Aerial photographs (Google Earth Maps) were used to acquire the land cover features of each measurement site. According to the results of some previous studies, air temperature in an urban location is mainly affected by its surrounding surface cover with a few hundred meters in

radius (Costa et al., 2007; Yokobori and Ohta, 2009; Yan et al., 2014). Thus, a buffer zone with 150 m in radius around each point was used for calculating vegetated and impervious fractions in our study. Using a similar method to Krüger and Givoni (2007), the percentage of impervious surface and vegetation cover for each measurement site were calculated with AutoCAD, by drawing corresponding areas on the aerial photograph. The detailed statistics of these landscape parameters are listed in Table 1.

2.4. Data treatment and analysis

During each traverse, the temperature at each measurement site is represented by an average of ten samples over a 50 m transect in order to avoid the influence of small variations. To avoid spurious data the 50 m average for each site cover a distance that do not include any stop by the bicycle. In addition, the abnormal temperatures resulting from nearby moving vehicles were excluded.

The air temperature difference between the measured values inside and outside the park was calculated to examine the variation in the intensity of the PCI during different time periods when observations were made. The independent samples *t*-test was used to test if there is any statistical difference between average temperature inside and outside the park. The correlation between the distance to the park and air temperature was examined to clarify the cooling effect of the large park on the surrounding urban area. Finally, critical landscape parameters affecting the air temperatures of each measurement site were analysed. For the analysis of data, *t*-tests and simple correlation analysis were performed by running the SPSS/PC + software package (SPSS, Inc.) on a personal computer. *P* values of less than 0.05 were regarded as statistically significant.

3. Results

3.1. Temperature profiles within the park and its surroundings

Fig. 2 shows the air temperature variation trend along the measurement route inside and outside the park at 14:00, August 16, 2010. The difference in air temperature inside and outside the park was not very obvious, and the air temperatures in the park were about the same or even somewhat higher than in the urban area. However, the lowest temperature was located in the central region of the park. To further explore the temperature profiles within the park and its surroundings, the average temperatures obtained at different measurement sites are presented in Fig. 3. The temperature difference between different measurement sites was not large, and the maximum average air temperature difference was 1.9 °C. The lowest air temperature of 35.0 °C was observed at site B9, near the park border, while the highest air temperature of 36.9 °C was observed at site B15, far from the park. Generally, the temperature at measurement sites inside the park was slightly lower than the temperature at measurement sites outside the park.

Fig. 4 shows the air temperature variation trend along the measurement route inside and outside the park at 19:00. At this hour, the temperature inside the park was noticeably lower than the temperature outside the park, and there was an obvious increase in temperature at the two sides of the park boundary. In particular, the increasing temperature trend was especially pronounced along the eastern edge of the park. Fig. 5 shows the distribution pattern of the average temperature at different measurement sites inside and outside the park at 19:00. The largest air temperature difference inside and outside the park was 1.8 °C. Overall, the lowest air temperature of 28.9 °C was observed at site B6, near the water area within the park. The highest air temperatures of 30.7°C were observed at sites B13 and B14, along the outer eastern edge of the park, where building density and human activity are relatively high.

Fig. 6 shows the air temperature variation trend along the measurement route inside and outside the park at 23:00. At this time, there were obvious differences in temperature within the field, with a cooler "core" in the park center compared to its warmer surrounding. Moving from the center of the park to the urban environment on the two sides outside of the park, the temperature tends to increase gradually. At a certain distance from the park border, the temperature gradually becomes steady. It is worth noting that slightly cooler urban

Table 1
Description of the measurement sites.

Site number	Location	Distance to park border (km)	Percent vegetation cover (%)	Percent impervious surface (%)	SVF
A15	Outside the park	1.4	30	65	0.91
A14	Outside the park	1.2	51	35	0.79
A13	Outside the park	1.0	69	28	0.76
A12	Outside the park	0.8	67	31	0.80
A11	Outside the park	0.6	54	42	0.87
A10	Outside the park	0.4	48	40	0.89
A9	Outside the park	0.2	41	51	0.93
A8	On the park border	0	26	67	0.91
A7	Inside the park	–	65	31	0.85
A6	Inside the park	–	67	29	0.86
A5	Inside the park	–	57	34	0.84
A4	Inside the park	–	71	24	0.92
A3	Inside the park	–	51	37	0.93
A2	Inside the park	–	66	27	0.87
A1	Inside the park	–	75	22	0.83
B1	Inside the park	–	73	24	0.90
B2	Inside the park	–	62	33	0.91
B3	Inside the park	–	53	43	0.92
B4	Inside the park	–	49	48	0.88
B5	Inside the park	–	47	49	0.89
B6	Inside the park	–	67	27	0.90
B7	Inside the park	–	61	34	0.86
B8	On the park border	0	38	56	0.93
B9	Outside the park	0.2	51	43	0.85
B10	Outside the park	0.4	32	55	0.84
B11	Outside the park	0.6	28	61	0.88
B12	Outside the park	0.8	7	89	0.86
B 13	Outside the park	1.0	6	91	0.90
B14	Outside the park	1.2	13	83	0.87
B15	Outside the park	1.4	26	65	0.84
B16	Outside the park	1.6	32	61	0.81

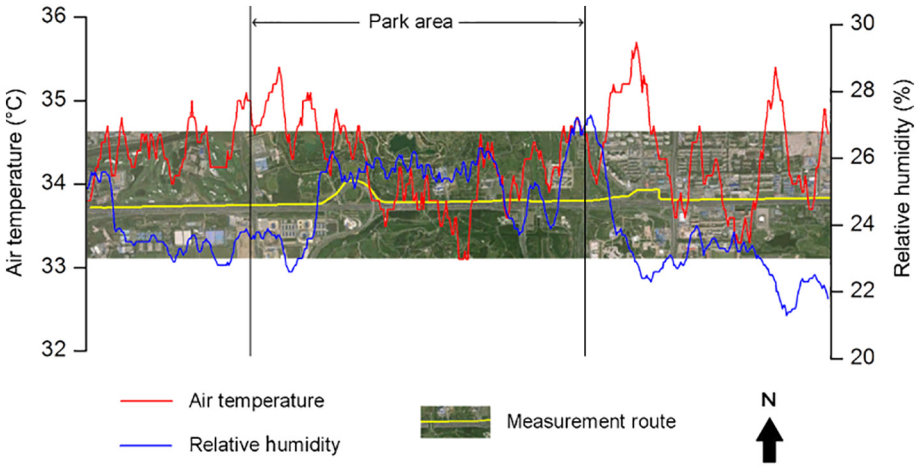

Fig. 2. Distribution pattern of temperature and humidity inside and outside the park at 14:00, August 16, 2010.

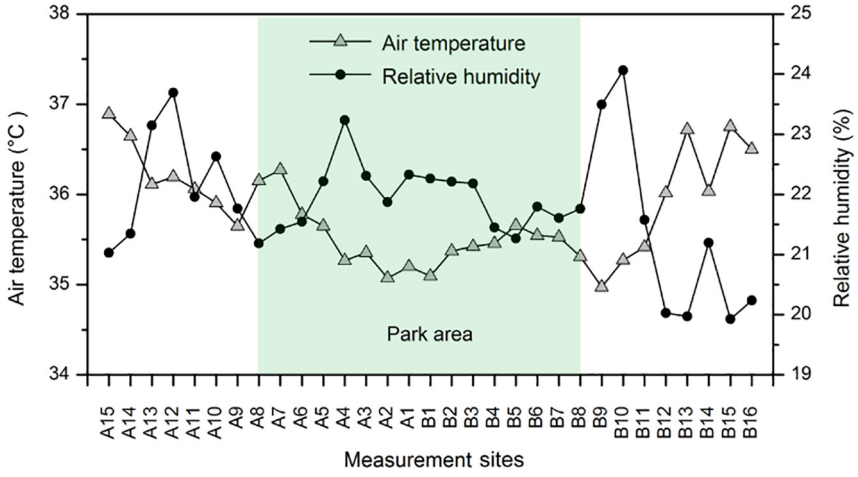

Fig. 3. Distribution pattern of average temperature and humidity at 14:00, considering all the field measurement days.

temperatures were observed in the west side, possibly indicating the effect of the surrounding urban features, with urban temperatures in the western section generally being ~1.5 °C cooler compared to the eastern section. Fig. 7 shows the distribution pattern of the average temperature at different measurement sites inside and outside the park at 23:00. The cooling effect of the park was extremely obvious, and the maximum temperature difference between the park and its urban surrounding was 4.6 °C. The lowest temperature of 21.8 °C was observed at site A2, which is located at the center of the park, while the highest temperature of 26.4 °C was observed at site B15, on the east side of park.

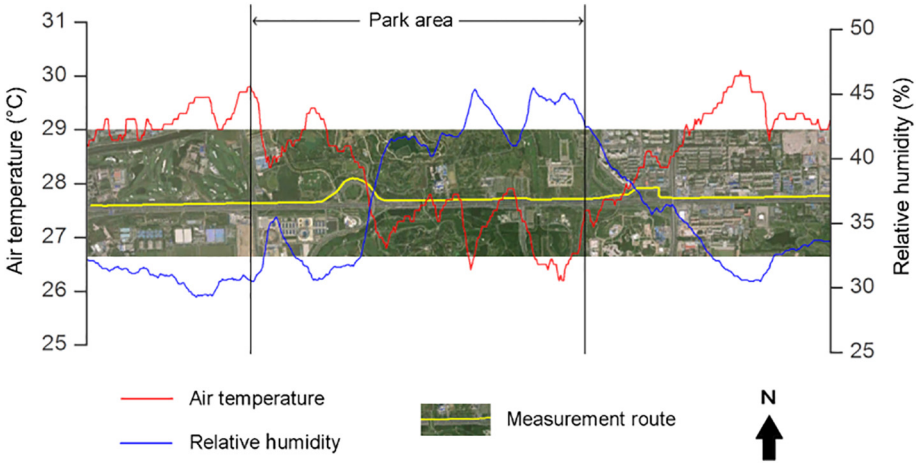

Fig. 4. Distribution pattern of temperature and humidity inside and outside the park at 19:00, August 16, 2010.

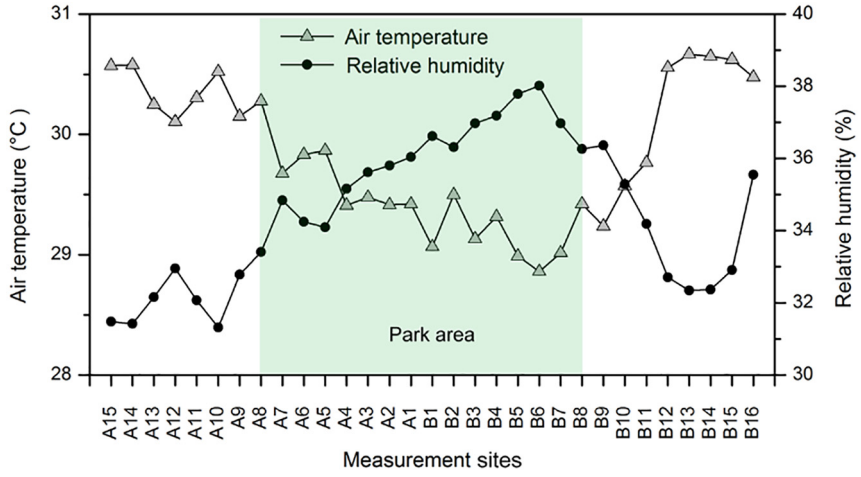
Air temperature
Relative humidity
Park area
Air temperature (°C)
Relative humidity (%)
Measurement sites
A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15 B16

Fig. 5. Distribution pattern of the average temperature and humidity at 19:00, considering all the field measurement days.

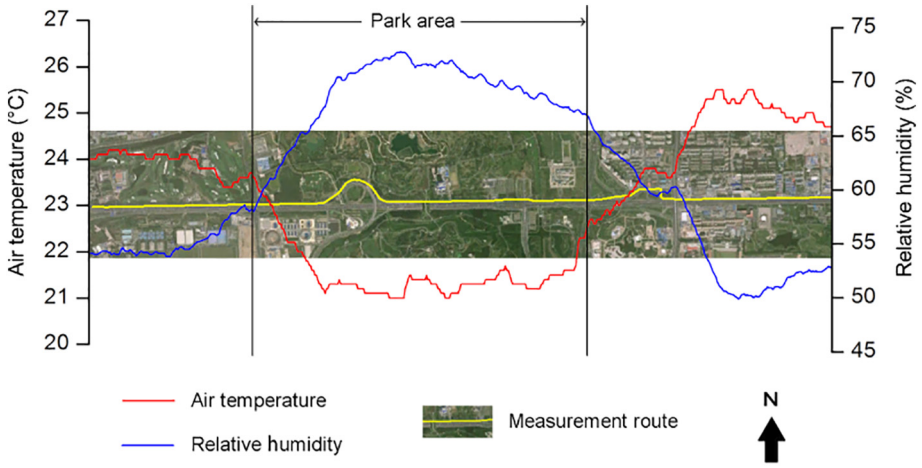

Fig. 6. Distribution pattern of temperature and humidity inside and outside the park at 23:00, August 16, 2010.

3.2. The mean park cool island intensity

Park cool island was usually calculated by subtracting the minimum park temperature from the maximum urban temperature. However, most urban and park environment are not homogeneous and therefore the average temperature provide a better explanation of the difference experienced between typical environments of a city. In this study, the mean park cool island was calculated in a similar manner but instead of the minimum and maximum temperature, the average temperature for their respective environments was used. The results indicate that at 14:00, 19:00, and 23:00, the temperatures inside the park were significantly lower than the temperatures outside the park, and the mean

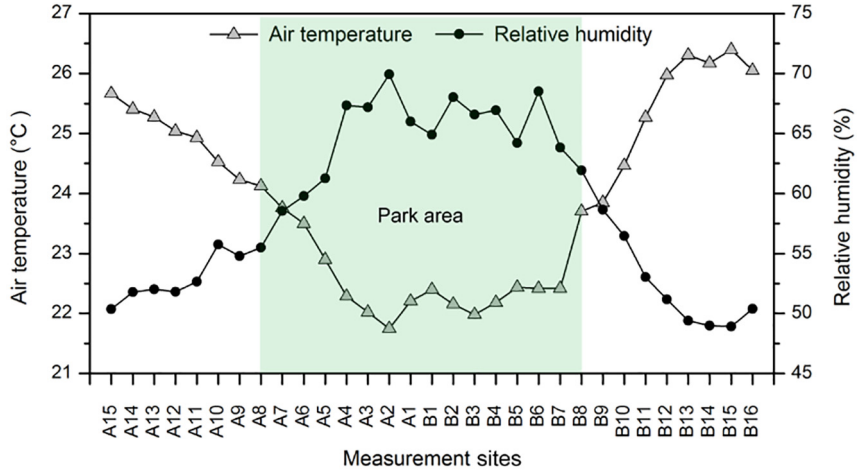
Air temperature
Relative humidity
Park area
Air temperature (°C)
Relative humidity (%)
Measurement sites
A15 A14 A13 A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1 B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12 B13 B14 B15 B16

Fig. 7. Distribution pattern of the average temperature and humidity at 23:00, considering all the field measurement days.

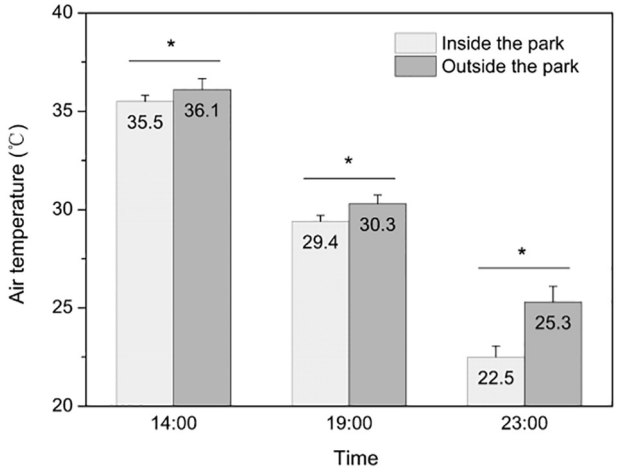

Fig. 8. Comparison of average temperatures inside and outside the park. (Note: * indicate significantly different means based on an Independent-Sample *t*-test at 0.05 level).

cool island intensity of the park was 0.6 °C, 0.9 °C, and 2.8 °C, respectively (Fig. 8). The other interesting thing to note is that the value of the standard deviation derived from the park area is smaller than that obtained from the surrounding urban areas. Therefore, the results indicate not only that these green spaces generate cooling effects that cause temperatures inside the park to be lower than temperatures in the surrounding urban environment but also that temperatures inside the park are more stable.

3.3. Influence of the distance to park on air temperature

The cooling effect of the park not only causes the mean temperature inside the park to be lower than the temperature outside the park, but also affects the surrounding urban environment. Fig. 9 shows that, for both route A to the west of the park and route B to the east of the park, the temperature exhibits an increasing trend as the distance from the park border increases. For route A, as the distance from the park margin increased, the air temperature continuously increased, and the cooling effect extended 1.4 km from the park. This cooling effect was most obvious at midnight, when the coefficient of determination R^2 was 0.982. For each 1-km increment in distance from the park border, the temperature increased by approximately1.13 °C. For route B, as the distance from the park border increased, the air temperature rapidly increased. At a distance of 1 km from the park, the temperature became stable, which indicates that the range of the park's cooling effect was approximately 1 km. The cooling distance of route B was tend to be smaller than the cooling distance of route A. However, the slope of regression analysis indicates that the cooling intensity of route B across the unit distance was visibly greater than that of route A. At 14:00, 19:00, and 23:00 the park's cooling intensity on the ambient environment was 1.08 °C/km, 0.95 °C/km, and 1.79 °C/km, respectively. This indicates that the urban environmental characteristics surrounding the park have an important influence on the park's cooling range and cooling

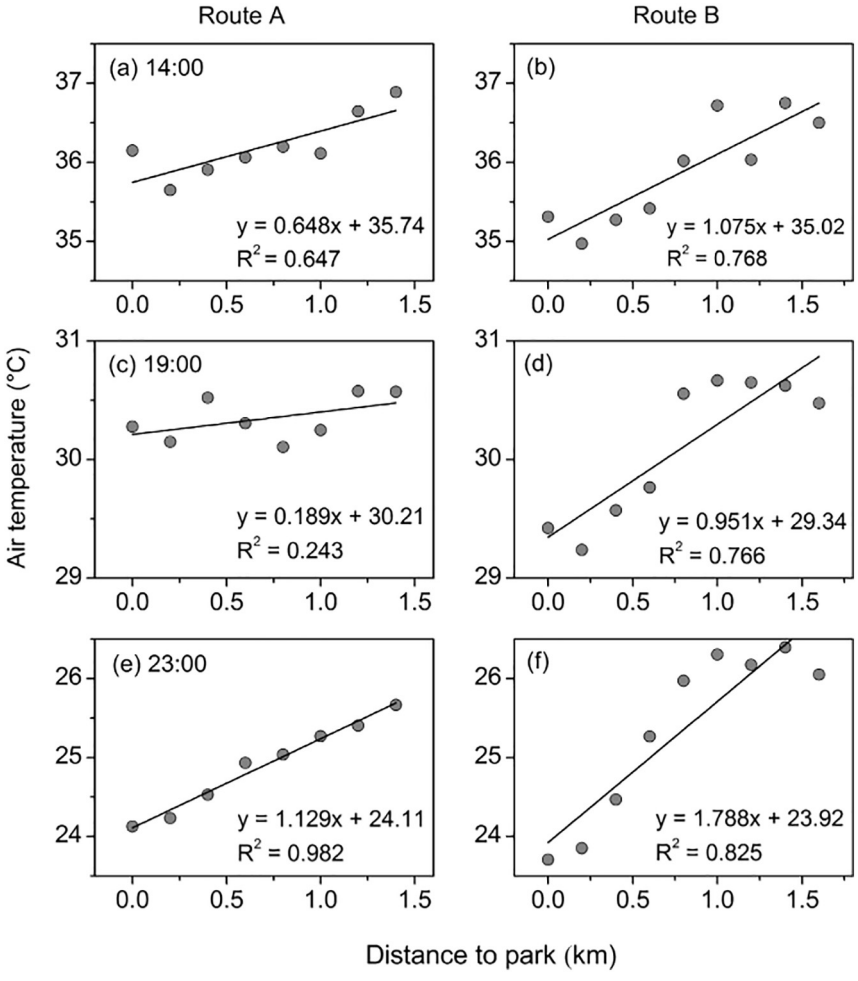

Fig. 9. Relationship between distance from the park and air temperature for every measuring location.

intensity. For route A, on the park's west side, there are few buildings and the terrain is open. Therefore, this area is favorable for increasing the park's cooling effect, and the cooling distance extends relatively far. However, because this area has a relatively greater amount of green spaces, low building density, and relatively low air temperatures, the park's cooling intensity is not high. Conversely, for route B, on the park's east side, there are many more buildings. In particular, the presence of medium-and high-rise buildings limits the extent of the park's cooling effect into the urban environment; therefore, the park's cooling distance is relatively short. However, because the environmental air temperature in this more urban setting is higher, the park's cooling intensity is markedly greater.

3.4. Influence of the land cover features on air temperature

Fig. 10 shows the linear regression results between the air temperature at 31 measurement sites and the land cover features within a 150-m radius. During the three observed time periods, the temperature exhibits a decreasing trend as the percent vegetation cover increases, and all linear regressions are negatively correlated, which also indicates that vegetation has a pronounced cooling effect. At 14:00, 19:00, and 23:00, when the percent vegetation cover increased by 10%, the temperature decreased by 0.12 °C, 0.17 °C, and 0.54 °C, respectively. The degree of correlation between the temperature and percent vegetation cover was highest at 23:00 ($R^2 = 0.481$), followed by 19:00 ($R^2 = 0.359$), and the degree of correlation was lowest at 14:00 ($R^2 = 0.216$).

In contrast to the cooling effect of vegetation, the increase of impervious surface area would significantly increase air temperature. At 14:00, 19:00, and 23:00, when the percent of impervious surface area increased by 10%, the temperature increased by 0.13 °C, 0.17 °C, and 0.55 °C, respectively. The degree of correlation between the temperature and the percent of impervious surface was highest at 23:00 ($R^2 = 0.470$), followed by 19:00 ($R^2 = 0.338$), and the degree of correlation was lowest at 14:00 ($R^2 = 0.224$).

4. Discussion

Urban green spaces have a pronounced cooling effect, a phenomenon that has been widely studied and validated in different regions and different cities (Spronken-Smith and Oke, 1998; Chen and Wong, 2006; Chang et al., 2007; Chow et al., 2011; Chen et al., 2012). In this study, we investigated and analysed the distribution pattern of air temperatures inside and outside the Beijing Olympic Forest Park through mobile observations. The results indicate that during different time periods, the air temperatures in the park were lower than the temperatures of the surrounding environment. This indicates that the park has

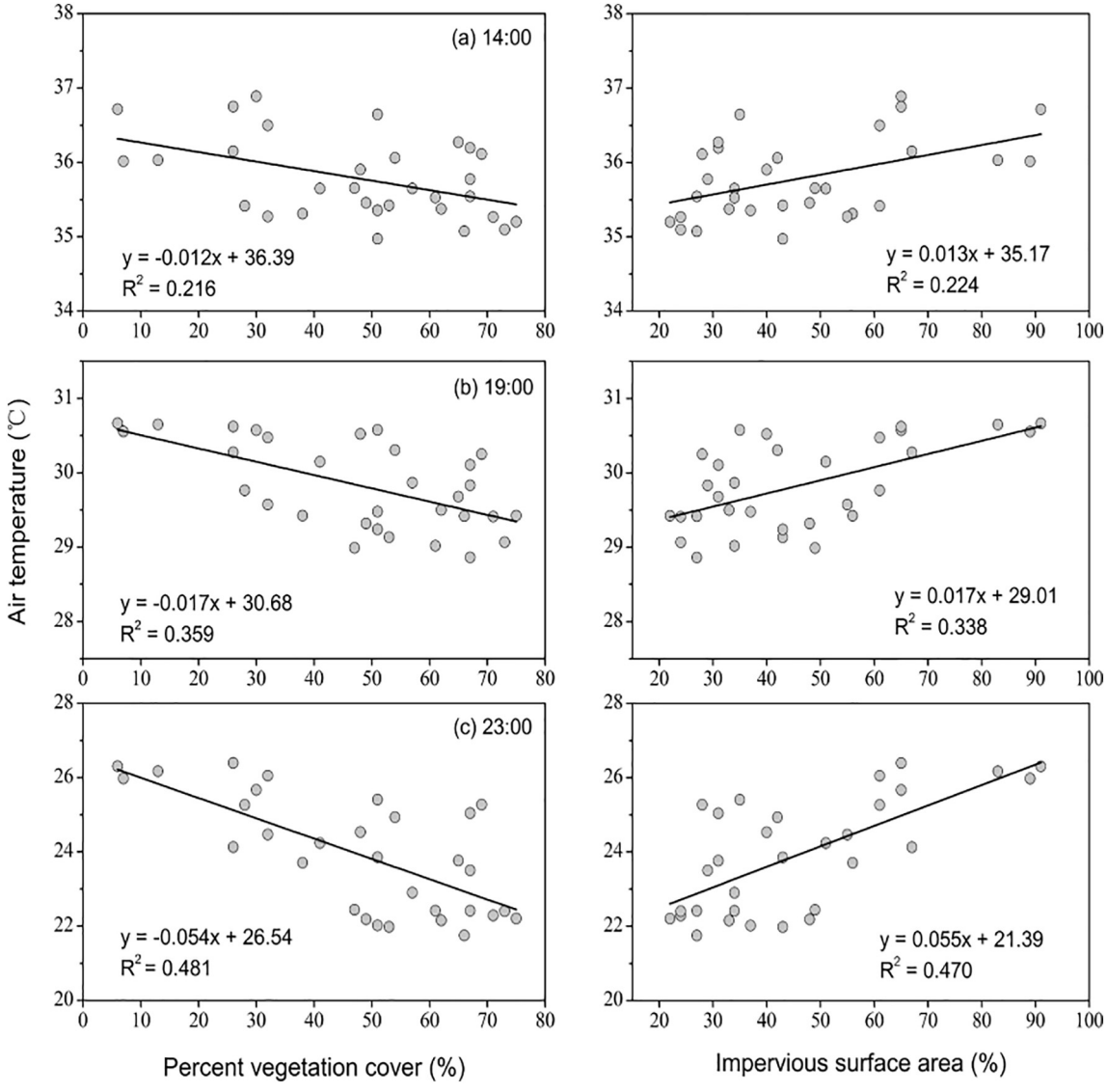

Fig. 10. Relationships between air temperature and land cover features for the percent vegetation cover and percent impervious surface area at different times.

an obvious cooling effect; however, there was a difference in the park's cooling intensity at different times. At 14:00, the park's cooling intensity was minimal; the greatest cooling intensity was 1.8 °C, with an average cooling intensity of 0.6 °C. At 19:00, the park's cooling intensity was similar to that at 14:00; the greatest cooling intensity and average cooling intensity were 1.8 °C and 0.9 °C, respectively. At 23:00, the park's cooling effect was most pronounced; the greatest cooling intensity was 4.8 °C, with an average cooling intensity of 2.8 °C Similar to the present study, Jauregui (1991) studied the cooling effect of a large urban park (~500 hm^2) in Mexico City. The results of that study indicate that due to the cooling rate of the park region being even greater after sunset, the park has the largest cooling effect at night, when the maximum cooling intensity can reach 3–4 °C. During the day, green spaces have a relatively small thermal inertia and a fast heating rate, which causes the cooling effect in the park to be less pronounced.

The park's green spaces not only cause the temperature in the park area to be less than the temperature of the ambient environment but also generate a cooling effect on the surrounding environment through the convection effect. The present experiment found that as the distance from the park border increases, the ambient air temperature exhibits a gradually increasing trend. The park had a cooling effect on the urban environments adjacent to the park's eastern and western edges, and this cooling effect extended approximately 1.4 km from the park boundary. In Mexico, Jauregui (1991) found that the radius for the influence of a large 500 hm^2 park on the environmental air temperature of surrounding cities was approximately 2 km, which is approximately the diameter of the studied park. In Japan, Hamada and Ohta (2010) showed that, at night, the cooling effect of urban green spaces can extend 200–300 m from a park's border; during the day, the cooling effect of green spaces can extend 300 m but does not exceed 500 m. At different times, the cooling effect of urban parks on the ambient environment varied. The cooling effect of the park was most pronounced at midnight, when the degree of correlation between temperature and distance variation was highest, and the cooling intensity was also greatest. This could occur because the temperature difference between parks and the ambient environment is greatest at midnight, when airflow is relatively stable, which is conducive to the diffusion of a park's cold air to the surrounding urban environment.

In addition, the urban environment outside of a park also affects the cooling effect. In this experiment, the park's cooling distance from its western edge, in an area characterized by low building density, was markedly greater than the cooling distance from the park's eastern edge, where building density is relatively high and the land cover has a complex composition. This primarily occurs because the land cover composition is simple and the building density is low in the western region. Specifically, there are few medium- and high-rise buildings, facilitating the diffusion of cold air in the park. Conversely, along the park's eastern boundary, the building density is high and there are many high-rise buildings. The street orientation is also intricate, which is not conducive to the circulation of cold air in the park. In Nagoya, Japan, Hamada and Ohta (2010) found that high buildings and wide roads with heavy traffic hinder the outward cooling effect of urban green spaces. Consequently, the cooling effect of urban green spaces on the ambient environment is affected by factors of the urban environment such as street orientation, building density, and the geometric structure of buildings (Shashua-Bar et al., 2006; Oliveira et al., 2011; Lau et al., 2012). Therefore, the reasonable planning and development of the built environment around urban green spaces can better utilize the cooling effect of urban green spaces.

There are a variety of urban land cover types, and different types of land cover comprise the “mosaic” urban land cover structure type. Because different types of land cover have varying thermal properties and thermal balances, each has a different influence on the surrounding surface temperature. Additionally, due to the convection effect, the temperature at any measurement site in the urban environment will be affected by the land cover composition of the surrounding environment up to a given range. Among the numerous land cover types, vegetative land cover produces a cooling effect on the urban environment due to evapotranspiration and shading influences. In this study, through a regression analysis on the temperature at different measurement sites and the percent vegetation cover within a 150-m radius, the temperature was found to exhibit a decreasing trend as the percent vegetation cover increases, which indicates that the vegetation has an evident cooling effect. In Taizhong City, Taiwan, Sun (2011) investigated the influence of percentage vegetation cover on the thermal environment of city streets and determined that vegetation has an evident cooling effect on street temperature; the higher the percentage vegetation cover is, the lower the street temperature. At moderate or large scales, many scholars use remote sensing imagery to study the relationship between urban vegetation status and land cover temperature, finding that the vegetation index and land cover temperature exhibit a significant negative correlation (Weng et al., 2004; Chen et al., 2006; Buyantuyev and Wu, 2010; Zhou et al., 2011).

However, there was a difference in the degree of correlation between temperature and percent vegetation cover at different times, as well as in the cooling intensity of vegetation. Generally, the degree of correlation between percentage vegetation cover and temperature was highest at midnight, when the cooling intensity of vegetation was also the greatest. In a suburban region of Tokyo, Japan, Yokobori and Ohta (2009) investigated the influence of land cover composition on the urban temperature and found that the degree of correlation between vegetation and temperature and the regulating effect of vegetation on temperature are both greater at night than during the day. Sun et al. (2009) also obtained similar results when they adopted the method of mobile measurements to study the heat island effect in Phoenix, Arizona. This phenomenon indicates that although vegetation does not have the cooling effect of evapotranspiration at night, because it has a higher cooling rate after sunset, vegetation still has a relatively strong cooling effect. Moreover, this cooling effect is even larger than the cooling effect generated by the evapotranspiration and shading effect of vegetation during the day (Sun et al., 2009; Yokobori and Ohta, 2009).

Contrary to the cooling effect of vegetation, impervious surfaces increase air temperature. In this experiment, for three different observation time periods, the temperature exhibited an increasing trend as the proportion of surrounding impervious surfaces increased, and there was a positive correlation for all time periods. During the day, influenced by solar radiation, impervious surfaces without evapotranspiration convert most solar energy to sensible heat and increase the temperature of the ambient air. During the day, impervious surfaces also store a large amount of heat energy, and at night, the heat energy stored during the day is slowly released and continues to heat the air. Therefore, impervious surfaces have a negative effect on the urban thermal environment throughout the day. Huang et al. (2008) studied the standard daily temperature variation for four land cover types (i.e., cement floor, grassland, forest land, and water body) in Nanjing, China, and reported similar results. The daytime temperatures for the four land cover types exhibited the variation trend of forest land < water body < grassland < cement floor, and the impervious cement floor increased the temperature. In Taiwan, Lin et al. (2007) investigated the influence of different pavement types on the outdoor thermal environment and found that in summer at noon, the surface temperature of impervious artificial pavement is approximately 10 °C higher than the vegetation surface temperature. Because air temperature is primarily affected by the nearby surface temperature, an impervious surface also has a significant influence on temperature. In Hokkaido, Japan, Shudo et al. (1997) quantitatively analysed the relationship between temperature and land cover composition based on a regression analysis, and their results indicate that developed environments dominated by impervious surfaces composed of cement and asphalt contribute to increased temperatures throughout the year. Therefore, due to compositional properties, impervious surface areas contribute to

increased air temperatures and have a negative influence on the urban thermal environment.

5. Conclusion

This study investigated the potential of a large park to mitigate the urban heat island effects of their surroundings. From observational results, it is found that the park is significantly cooler than the surroundings built-up area during the day and at night, but especially so during the midnight period. This effect is noticed not only within the boundaries of the green area, but extends beyond the park itself, and that cooling effect, while variable, can extend almost 1.4 km beyond the park's border. At the same time, it is worth noting that the standard deviation of temperatures obtained from the park area is smaller than that derived from the surrounding urban environment. It provides the evidence of the ability of green areas on stabilizing the fluctuation of the temperatures than that of the urban built-up area. These results confirm the potential contribution of green areas as an effective way of improving the urban microclimate, as well as mitigating the heat island effect. Large differences in air temperature exist both within the park area and within the surrounding built-up areas. These differences depended strongly on the land cover characterizing the immediate environment of the measurement sites. Therefore, the location of the measuring sites is very important for any comparison with other studies.

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

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